The search for ^{271}Mt via the reaction ^{238}U + ^{37}Cl

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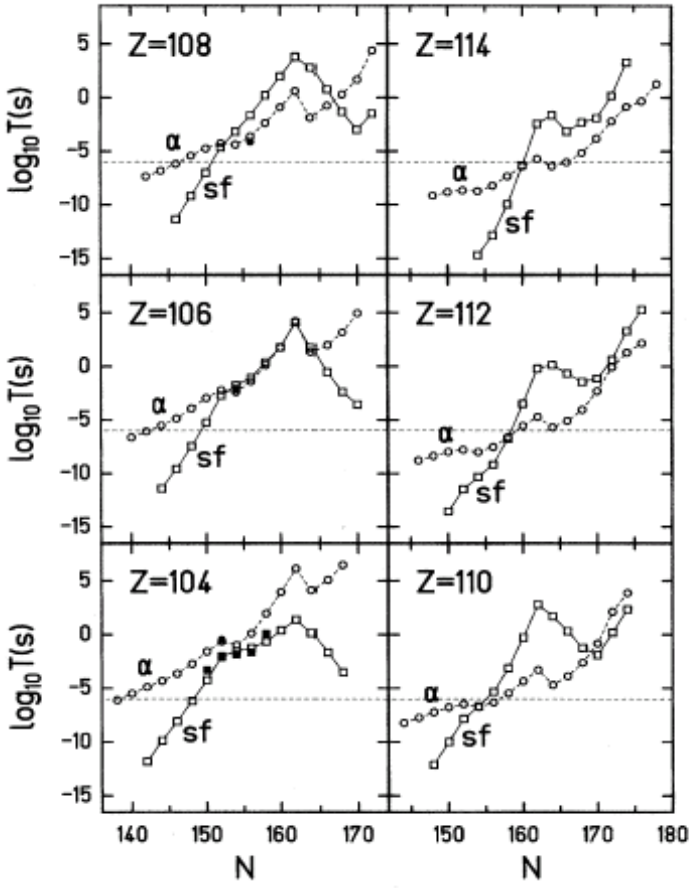
Introduction

Theoretical calculations show that, in the region of the heaviest elements, liquid drop fission barriers tend to decrease to zero. Therefore, the occurrence of nuclear shells is of special importance for the stability of nuclei [1,2]. Experimentally, the influence of deformed sub-shells at Z=108 and N=162 have been confirmed, with the 300-fold increase in half-life of ^{269}Hs$_{161}$ compared to ^{267}Hs$_{159}$ [3] and our recent discovery of ^{270}Hs$_{162}$ with collaborators in Europe [4]. Production of ^{271}Mt$_{162}$ would allow further examination of the N=162 sub-shell. There are many valid reasons to produce ^{271}Mt:

This reaction type (^{238}U + medium mass projectile) provides access to many nuclides near the deformed sub-shells. The 88-inch cyclotron can provide high intensity beams of projectiles with A~40 and we have calculated BGS efficiencies in a range of 30% for this reaction type. This type of reaction may have important implication with respect to the chemical study of nuclides with Z > 108.

The cross section for the production of a compound nucleus is influenced by shell effects. The projectile N=20 shell results in lower E* when fusing at the Coulomb Barrier (^{37}Cl$_{20}$), and the doubly-magic deformed shell of ^{270}Hs helps with the Γ_n/Γ_f exit channel, especially at the point where the fourth neutron is evaporated [5].

Alpha-decay systematics can be estimated by comparison with ^{270}Hs and ^{272}110, indicating a half-life of ^{271}Mt ~2 seconds. Both ^{270}Hs and ^{272}110 are dominated by α-decay even though as even even nuclei they are unhindered, and are predicted to have a half-lives of 5s and 1,400μs, respectively. Comparing the ^{271}Mt alpha-decay energy provides us with quantitative information on the strength of the shells as shown in the figure below [1]. We expect ^{271}Mt to decay primarily by α-decay, which would produce ^{267}Bh and ^{263}Db. Production of these nuclides would provide more information on their (α and sf) branching ratios.



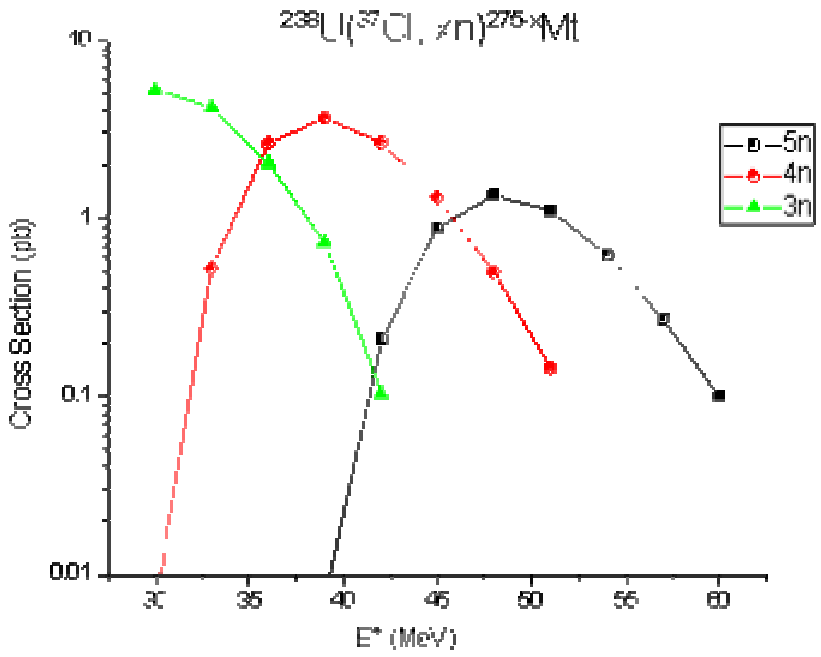
Below are some of ^{271}Mt's predicted alpha decay partial half lives.

Q_α (MeV)	$T_{1/2}$ (s)	Reference
9.91	~10^{-4}	I. Muntian, et al. [6]
10.14	~10^{-6}	G. Royer and R.A. Gherghescu [7]
9.3	26.92	P. Möller, et al. [8]
9.45	1.58	S. Cwiok, et al. [9]

Spontaneous fission may play a significant role in the decay of ^{271}Mt even though odd-A nuclides are hindered with respect to this decay mode as compared to their even even counterparts.

Lastly, discovery of a long-lived (> 1s) isotope of Mt would allow the first-ever chemistry experiment of this element. Presently, the highest Z atom to be studied chemically is Hs, in work that our group collaborated with colleagues in Europe [10], and extension of the Periodic Table to Mt would represent an important advance in basic science.

We expect to produce ^{271}Mt via the ^{238}U(^{37}Cl,4n) reaction. Our motivation for this target-projectile combination comes from recent work at Dubna [11] where they reported a 2.5pb cross section for the reaction ^{238}U(^{34}S,5n) ^{267}Hs, and the identification of three atoms of ^{267}Hs. We have run HIVAP (with the Schädel parameters) for our proposed reaction, shown below:



Lighter Mt isotopes were first synthesized in 1982 by Münzenberg and collaborators [12]. Meitnerium's chemistry has never been studied due to the fact that its two known isotopes (^{266}Mt and ^{268}Mt) have half-lives much less than one second. In order to perform the first-ever chemistry of Mt, one would first need to synthesize a longer-lived isotope. Hulet and collaborators attempted such an experiment [13], but were only able to establish a 1 nb cross section upper limit on the formation of ^{272}Mt.

Experimental

Uranium targets were produced at Oregon State University by evaporating a thin layer of UF_4 upon a 2 μm thick Al foil. Uranium thickness was measured by weighing, and uniformity and thickness were confirmed by counting small sections of a target in an α-chamber. For the third run, average target thickness was 400μgU/cm^2; the two earlier runs were similar.

Reaction products were separated in flight by the Berkeley Gas-filled Separator (BGS) and implanted in the focal plane detector. The focal plane detector consists of a five-sided box of vertical Si strips measuring 18cm x 6cm x 6cm; using this array of strips we can determine the horizontal and vertical position of the event in addition to the energy and elapsed time. The four box sides (referred to collectively as the upstream detectors) are used to record escape α's during our beam shutoff period. In addition, a multi-wire avalanche counter (MWAC) was mounted upstream of the focal plane detector, and a Si detector was mounted downstream of the focal plane as a punch-through detector. Both the MWAC and the punch-through detectors functioned to veto uninteresting events in the focal plane.

We employed an automated beam chopper in this experiment. During the experiment, should a correlated EVR-α event occur with certain time and energy windows, the beam would be deflected away from the target chamber for a set period of time. Should another correlated α be recorded, the beam shutoff would be continued for another set period of time. Deflecting the beam allows the upstream detectors to be utilized without the interference of scattered beam.

Discussion

A complicating factor encountered in carrying out this experiment as well as data analysis is that the evaporation residues lose most of their energy as they transit through the MWAC, resulting in implant energies below 1MeV (signals below 500keV). Indeed, steps were taken to reduce the amount of material encountered by the EVRs, especially in replacing the PPAC with an MWAC. We ran test reactions during this experiment, producing Fr and Es isotopes, to measure their range in the MWAC and confirm published range tables. We have concluded that our ranges were 15% less than published data. We plan to reduce the effective thickness of the MWAC from 3.3μm mylar to 2.4μm mylar in order to increase the EVR implant energy.

The Heavy Element Group at LBNL led an attempt to synthesize ^{271}Mt at the LBNL 88-inch cyclotron. The reaction of 195MeV (center of target) ^{37}Cl + ^{238}U was carried out in a series of three experiments during November 2002 & April/May 2003. Total beam dose delivered during these three experiments was 3.2×10^{18} particles. Data analysis is in progress, though no correlated decays attributable to the Mt-Bh-Db-Lr chain have been seen so far, leading to a single event upper limit cross section of 0.63pb. Future experiments at higher beam energy are planned to further explore the 4n and 5n exit channels with this beam and target combination.

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